MATERIALS BUREAU

TECHNICAL REPORT 89-4

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NEW YORK STATE DEPARTMENT OF TRANSPORTATION
MARIO M. CUOMO, Governor
FRANKLIN E. WHITE, Commissioner

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## LABORATORY TESTING OF REGULATED-SET PORTLAND CEMENT (RSPC) HIGH EARLY STRENGTH CONCRETE


Prepared By

David W. Bernard, P.E.
Civil Engineer II (Materials)



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MATERIALS BUREAU
JAMES J. MURPHY, DIRECTOR

NEW YORK STATE DEPARTMENT OF TRANSPORTATION
1220 WASHINGTON AVENUE, ALBANY, NY 12232



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## ABSTRACT

The purpose of this study was to investigate the material properties of a newly developed portland cement through laboratory analysis. The product is Ideal's Regulated-Set Portland Cement (RSPC). This new cement is proposed for use in high early strength concrete mixes used for pavement or structural repairs requiring rapid initial strength gain. The manufacturer claims slab replacements completed using this concrete can accept traffic within two hours of placement.

Ideal's Regulated-Set Portland Cement (RSPC) differs from conventional Portland cements. The RSPC is modified in manufacture by replacing the tri-calcium aluminate with calcium fluoro-aluminate. This change produces concrete with short set times and rapid strength gain. The manufacturer claims a compressive strength of 2500 psi is possible in three hours. Laboratory testing of different concrete mixtures was completed to document the physical properties of concrete incorporating this new cement.

## BACKGROUND

High early strength concrete has been available in New York State for many years. It has been used in the (removal and) replacement of isolated concrete pavement segments in recent years. The high early strength concrete can minimize construction costs by shortening lane closures for road repairs. The decision to use a more expensive high early strength concrete (compared to conventional mixes) to repair pavements can be justified because of savings in terms of user delay costs or maintenance and protection of traffic costs. The shorter lane closures possible using high early strength concrete can have a substantial impact on lowering traffic associated costs.

Since 1981, various types of high early strength concrete have been used in New York State. In particular, downstate areas have utilized calcium chloride accelerated concrete (using Type III Portland cement) and Rapid Setting Concrete (RSC) repair materials for PCC pavement repairs. Calcium chloride accelerated concrete is used for repairing larger pavement replacement areas where lanes cannot be closed to traffic for any extended period of time. Lanes closed for repair are typically reopened to traffic four hours after placement. RSC repair materials are typically used for smaller patches where it is convenient to mix small amounts at a time. For the larger slab replacements, the cost of RSC repair materials eliminates them as alternatives, compared to calcium chloride accelerated concrete.

Calculations show the minimum compressive strength of concrete needed to resist the bearing stress of the load transfer dowels is 2000 psi. Once this strength is reached, the pavement can be opened to traffic. Thus, 2000 psi has been established as the criteria for determining when traffic will be allowed back onto a concrete repair area.

# LABORATORY MIX DESIGNS

The following mix designs are the result of five trial laboratory mixes completed to test for workability, set times, slump, air, compressive strength, and durability.

| PARAMETERS | MIX NUMBER 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| W/C Ratio | .375 | .35 | .375 | .35 | .35 |
| Cement (lbs/yd.$^3$)* | 752 | 752 | 752 | 752 | 752 |
| Water (lbs/yd.$^3$) | 281 | 263.5 | 282 | 263.5 | 263.5 |
| Sand (lbs/yd.$^3$) | 1151 | 1170 | 1151 | 1151 | 1417 |
| Stone (lbs/yd.$^3$) | 1686 | 1686 | 1686 | 1686 | 1417 |
| Air Dosage (oz./100 lbs cement) | 1.5 | .65 | .81 | .81 | .81 |
| Slump (inches) | 12 | 3/4 | 8 | 8 | 11 @ 1 min.<br>5 @ 12 min.<br>2.5 @ 17 min. |
| % Air (%) | 12 | 2.2 | 8 | 7.6 | 6.7 |
| Initial Set (min.) | 15 | 5 | 13 | 13 | 25 |
| Unit Wt. (lbs/ft$^3$) | 134.8 | 152.9 | 142.8 | 144.3 | 145.2 |
| Strength Gain hrs. | 1400 psi/2.5 hrs. | N/A | 2400 psi/3.0 hrs. | 2600 psi/3.0 hrs. | 2200 psi/3.0 |
| Retarder at cement | - | - | - | - | citric acid .1% wt. of |

* Cement used is Ideal's Regulated-Set Portland Cement. Cement is modified with calcium floro-aluminate in place of tricalcium aluminate found in normal portland cement.

## LABORATORY TESTING

The following summary documents the laboratory analysis performed on Ideal's Regulated-Set Portland Cement. The mix design variables were adjusted to achieve the best possible combination of physical properties in the concrete. The mix proportions are given on Page 3.

### Trial Mix #1

The laboratory analysis began with a water/cement ratio of .375, incorporating eight sacks of cement (752 lbs.) per cubic yard. The initial percentage of sand in the mix was 40%. The dosage rate of air agent (Sika AEA) was estimated at 1.5 oz./100 lbs. cement.

The physical properties of the mix were not desirable. The mix was too soupy, estimated at a 12" slump. The air agent dosage rate was too high, producing 12% entrained air. The set time was very short, and it was difficult finishing some of the 4"x8" cylinders. The high air content adversely affected the compressive strength. Subsequent mixes should attempt to lower slump and air content and extend the initial set times.

### Trial Mix #2

In an attempt to lower the slump, the mixing time was doubled from 3 minutes to 6 minutes. Since this cement differs significantly from normal Portland cement, the cement and water was given more time to react together.

The extended mixing time caused the mix to set prematurely. No cylinders were cast for strength. The manufacturers recommendation for mixing times between 2-3 minutes should be strictly adhered to.

### Trial Mix #3

In an effort to adjust the undesirable physical properties of this mix, the entrained air variable was changed first. The air dosage rate was lowered to .81 oz/100 lbs. of cement and all the other mix proportions were held constant compared to Mix #1.

The lowered air dosage rate produced 8% entrained air. This is acceptable, however it is at the high end of the desirable range. The slump was still too high and the setting time was still rather short. Mix #3 produced compressive strengths of 2400 psi in 3 hours.

### Trial Mix #4

Since the air dosage rate was corrected in Mix #3, the next variable we attempted to adjust was the slump, which was at 8". In an effort to lower the slump, the water/cement ratio was lowered from .375 to .35, holding all other mix parameters constant compared to Mix #3.

The lower w/c ratio of .35 did not effect the slump appreciably, remaining around 8". The air content did decrease slightly to 7.6% with an associated slight increase in unit weight. The lower w/c ratio (.35) did have a slight impact on early compressive strengths, increasing them to 2600 psi in 3 hours.

Trial Mix #4 (continued)

At this point, the slump was initially 8", but was decreasing rapidly. The concept of "rate of slump loss" was developed and considered more meaningful for this type of cement, which would be determined on subsequent mixes. Also, in an effort to lower the slump, the percentage of sand was changed from 40% to 50%, increasing the overall surface area of the mix. The mix was also retarded using citric acid to extend the working time.

Trial Mix #5

The increased percentage of sand in Mix #5 (compared to the other mixes) seemed to produce a creamier, more workable mix. The "rate" of slump loss was measured, showing a dramatic drop in slump over the first 20 minutes. The increased sand content did effect the air percentage, lowering it to 6.7%, which is acceptable and desirable. The citric acid added as a retarder did extend the initial set time from 13 to 25 minutes, at a dosage rate of .1% by weight of cement. The retarder had an effect on early compressive strength gains, decreasing them to 2200 psi in 3 hours.

At this point, laboratory testing was concluded because a satisfactory compromise had been achieved between slump, air, set time, and compressive strength gain. Mix #5 is recommended for the mix design, if Ideal's Regulated-Set Portland Cement is used as a Concrete Patch material.

## Results of Laboratory Analysis

1) The consistency of concrete produced using Ideal's Regulated-Set Portland Cement (RSPC) is very soupy.

2) For the eight sack mix used, the average initial slump was between 8"-11" for concrete incorporating Ideal's RSPC.

3) The slump is not constant with time, changing considerably during the first 20 minutes. (See Page 3, Mix #5, Slump)

4) Citric acid was used as a retarder to extend the initial set from 15 minutes to 25-30 minutes. The citric acid was added at a dosage rate of .1% by weight of cement (752 lbs. cement/yd$^3$).

5) The compressive strength of cylinders tested after 3 hours decreased from 2600 psi to 2200 psi when retarder was used.

6) Freeze-thaw results showed 0% loss for 4"x8" cylinders cast from Mixes 1, 3, 4, using a 10% NaCl solution for 25 cycles.

7) The manufacturer's recommended dosage range for Sika AEA is between .75 to 1.5 oz/100 lbs. of cement. Our laboratory analysis found .81 oz./100 lbs. of cement as appropriate. It is unusual this low a dosage rate would produce adequate entrained air considering the cement factor was 752 lbs. of cement/yd$^3$.

## CONCLUSIONS

1) A concrete retarder is necessary to achieve extended initial set times for field applications. Without a retarder, the concrete sets too rapidly.

2) Citric acid, recommended by the manufacturer, is an acceptable retarder, confirmed by laboratory analysis.

3) Based on laboratory experiments and the manufacturers literature, retarding the concrete beyond .1% by weight of cement is not recommended. Retarding the concrete beyond this point would sacrifice 2000 psi initial strength gain.

4) The durability of the concrete was acceptable, based on freeze-thaw testing and an entrained air content between 6-8%.

5) RSPC achieved adequate initial compressive strength (see Page 3 Strength).

## RECOMMENDATIONS

1) Following our laboratory analysis, Mix #5 is recommended as an acceptable mix design for Ideal's RSPC.

2) RSPC is recommended only for use in concrete mobiles or small drum construction mixers, because of the accelerated initial set times without retarders (approx. 15 minutes).

3) The shorter mixing times associated with the concrete mobile (15-20 seconds) should be evaluated in the field to determine if this is long enough to mix the water and cement completely.

4) RSPC is not recommended for transit mix distribution for fear of premature setting in the truck.

5) Field demonstration projects are recommended using RSPC for concrete pavement segment replacement.

6) An acceptable procedure should be developed to control water consistency. Slump may not be appropriate since it varies considerably with time.

7) For small construction mixers, the manufacturers recommendation for mixing times between 2-3 minutes should be strictly followed.

# APPENDIX

## LABORATORY MIX DESIGNS

| MIX # | REMARKS | RECOMMENDED ACTION |
|---|---|---|
| 1 | - Air % too high<br>- Slump too high<br>- Initial set too short | - Lower air agent dosage<br>- Adjust water/cement ratio<br>- Extend initial set |
| 2 | - Mixing time was doubled mix set prematurely, no cylinders cast for strength | - Mixing time should follow manufacturers recommendations between 2-3 minutes only |
| 3 | - Air % has been lowered into an acceptable range<br>- Slump still too high<br>- Initial set still too short | - Keep air dosage the same<br>- Lower w/c ratio<br>- Increase setting time using retarder |
| 4 | - Air % still good<br>- Slump still too high<br>- Setting time too short | - Keep air dosage the same<br>- Keep w/c ratio same<br>- Increase % sand in mix to lower slump<br>- Extend initial set using a retarder<br>- Determine "rate" of slump loss |
| 5 | - Air % good<br>- More sand (50/50) seems better<br>- Citric Acid used as a retarder extends initial set 15-20 minutes at .1% by wt. cement<br>- Slump varies with time<br>- Retarder slowing initial strength gain | - End Testing |